LORENTZ TEM INVESTIGATION OF MAGNETIC DOMAINS IN EPITAXIAL C-AXIS ORIENTED Co-Cr THIN FILMS

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Continuous increase in recording densities of the Co-based longitudinal media requires a drastic scaling down of the grain size in order to keep the required signal to noise ratio. However, this approach to increase the areal density will collapse when the grain size reaches the superparamagnetic limit. As an alternative, based on the analysis of the demagnetization mechanisms, Iwasaki and Takemura[1] suggested the possibility of perpendicular magnetic recording (PMR), and computer simulation[2], predict areal densities of more than 300Gbit/in^2 for this configuration. The c-axis oriented Co-based hcp alloys with the magnetocrystaline anisotropy larger than the demagnetizing energy [3], are good candidates for the PMR media. However, before this type of materials can be realized, the magnetic domain structure must be well characterized. In this paper detailed analyses of the characteristics and shape of the magnetic domains present in the c-axis oriented CoCr films with thickness relevant for the recording industry are discussed.

Single crystal c-axis oriented $Co_{0.95}$-$Cr_{0.5}$ films were grown on Si(111) using a 500Å Ag underlayer to facilitate epitaxial growth by reducing the lattice mismatch (FIG. 1). The growth conditions are explained in more detail elsewhere.[4] A θ-2θ X-ray diffraction scan showed only Si(111), Ag(111) and Co-Cr(0002) peaks, indicating an epitaxial growth and closed pack hexagonal structure of CoCr layer, with the c-axis oriented normal to the film plane. In addition, the corresponding rocking curves, θ-scans, for the Ag(111) and Co-Cr (0002) peaks show a very narrow full width half maximum of 0.59° and 1.14°, implying a narrow dispersion of the (111) and (0002) of the Ag and Co-Cr layers, respectively. Transmission electron microscopy (TEM) revealed an average "grain" size of 30 to 50 nm and the indexing of the selected area diffraction (SAD) pattern of the plan-view samples confirmed the following epitaxial relationship: $(111)_{Si} \parallel (111)_{Ag} \parallel (0001)_{CoCr}$; $[-220]_{Si} \parallel [-220]_{Ag} \parallel [-1100]_{CoCr}$. Moreover, the Ag and Co-Cr spots exhibit arcs comparable to that of the Si substrate confirming that the rotation of the subgrains about the $[111]_{Ag}$ and $[0001]_{CoCr}$ axes is small ($\leq 3^o$).

The magnetic domains of these films, as a function of thickness (t) and temperature, were investigated by Lorentz microscopy in a Philips CM200FEG TEM fitted with a Gatan Imaging Filter (GIF) using Fresnel, Foucault and differential phase contrast (DPC) imaging methods.[5,6] The analysis of the Fresnel images of the wedge shape TEM sample prepared by low angle ion-milling with the thickness varying from 200Å - 700Å, revealed two types of domain configuration. The local thickness of the sample was obtained from measurements of inelastic mean-free path lengths in transmission electron energy-loss spectroscopy (EELS)[7] Below a certain critical transition thickness $t_c \approx$ 300Å the magnetization is in-plane, and the film supports large domains with size varying between 0.6 - 1μm, with relatively straight domain walls. Above t_c a regular stripe pattern[8] was observed, with stripe period increasing gradually with thickness, from ~90nm at t=300Å to ~110nm at t=700Å (FIG 2). In this region the magnetization is effectively in-plane with an out-of-plane component, and the stripe-like pattern is due to up and down periodic modulation of the out-of-plane magnetization component. Figure 3 shows the TEM DPC[9] analysis of the in-plane magnetization component of the stripe like domains. Figures 3a, b, c and d are the sums of the series of 15 images recorded at incremental beam tilts in +X, -X, +Y, and –Y directions respectively. The two orthogonal components of the in-plane magnetization vector are shown on Figures 3 e and f and these are respectively U = (+X, Fig3a) – (-X, Fig 3b) and V= (+Y, Fig3c) – (-Y, Fig3d). The vector plot of the U and V components is presented in Figure 4. The regions with no arrows indicate areas of the sample where the magnetization has no in-plane component and is out of plane. The length of the arrows corresponds to the magnitude of the in-plane component of the magnetic induction. Hence, it can be concluded that the stripe domains arise from alternating out of plane magnetic components, with significant in-plane component in the transition regions. This conclusion is in good agreement with the out of plane magnetic measurements[4], which show wasp like structure characteristic for the up and down stripe patterns.[10]

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11. Greg Kusinski acknowledges; IBM financial support through the "IBM Research Fellowship", research guidance from Prof. Gareth Thomas and Dr. Kannan Krishnan, and technical help from Chris Nelson, John Turner, Doreen Ah Tye and Chung Yu Song. Work at NCEM was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098

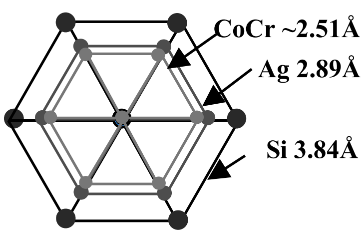

FIG. 1. Orientation relationship used in the epitaxial growth of CoCr. Lattice misfits for the respective close pack planes:
$[a_{Si}\text{-}a_{CoCr}]/a_{CoCr} = 52.99\%$
$[a_{Si}\ \text{-}a_{Ag}]/\ a_{Ag} = 33.93\%$
$[a_{Ag}\text{-}\ a_{CoCr}]/\ a_{CoCr} = 15.14\%$

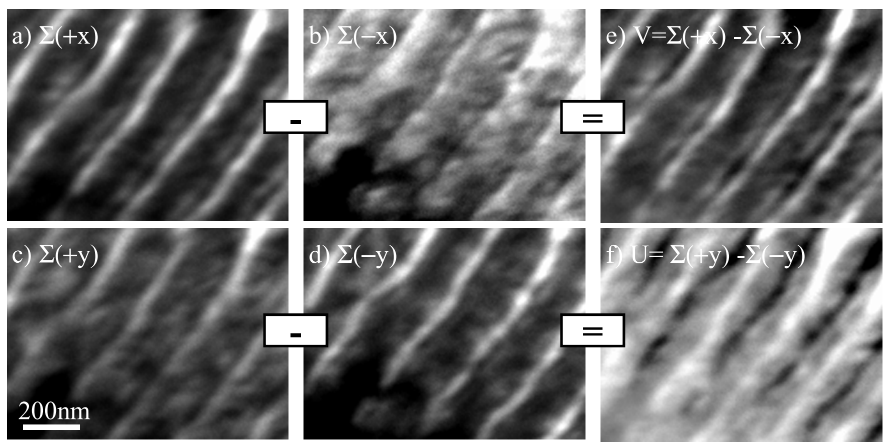

FIG. 3. (a, b, c, d) images obtained by performing the TEM DPC technique. The differential signal images, (e, f) are proportional to in-plane magnetization.

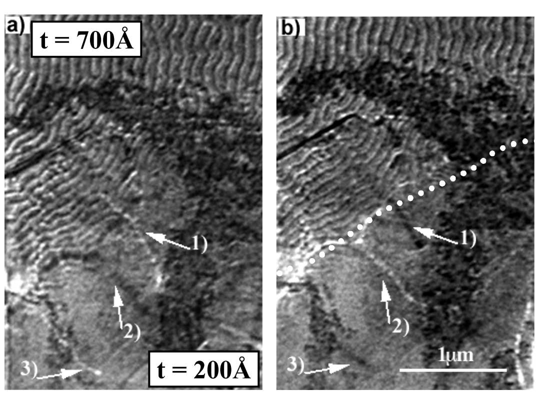

FIG. 2. Complementary set of Fresnel images showing thickness dependent magnetic contrast. Critical thickness, t_c=27.2(A)$^{1/2}$(M$_S$)^2/K$_u$ = 300Å (@RT), is showed with a dashed line. Domain walls below t_c are labeled with numbers.

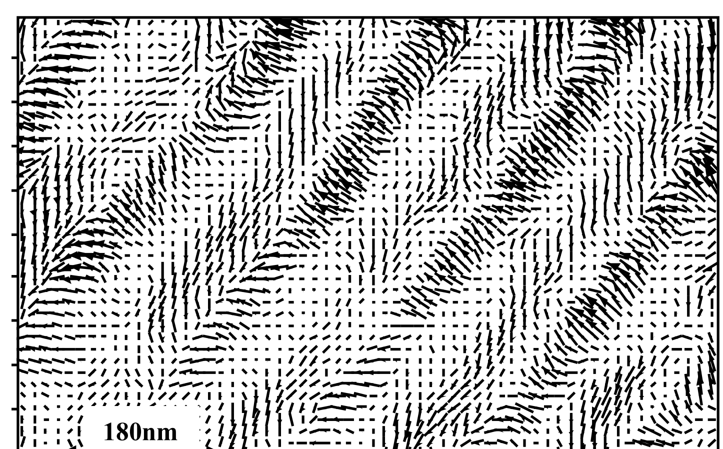

FIG. 4. Vector plot based on the U and V components from FIG. 3. The length of the arrows corresponds to the magnitude of the in-plane component of the magnetic induction.